Chapter 2
Background and Literature Survey

In the last decade, a large number of works on energy-efficient, high-quality and low-cost wireless access services have shown up [1–3]. Generally, these solutions can be divided into two classes, namely, customer-oriented and infrastructure-oriented solutions. Customer devices, e.g., wireless sensor nodes [4] and mobile terminals, usually are powered by batteries. Thus, the research objective of customer-oriented solutions mainly focus on improving energy efficiency to prolong the battery lifetime by various methods including energy-efficient software applications [5], hardware design [6], and protocol improvements [7]. Compared with customer devices, the network infrastructure contributes to the dominant portion of the total energy consumption of the system. For example, the BSs consume 60–80 % of the network's energy consumption [8, 9]. Therefore, it is more important to reduce energy consumption of the infrastructure in order to improve the energy efficiency of the overall system. To sustain the wireless operations, one promising solution is to use green energy to power the infrastructure network devices. In such a sustainable network, the research objective and performance metric are changed from energy efficiency to energy sustainability, i.e., to ensure harvested energy can sustain the normal network operations. We categorize the existing works in the literature related on sustainable wireless networks into three research issues: (1) network planning, (2) energy modeling, and (3) resource allocation.

2.1 Network Planning

Network planning has been extensively studied in the context of different wireless networks, including cellular networks, IEEE 802.16 WiMAX, and sensor networks [10–12]. Network planning is usually formulated as device deployment optimization problems, aiming at maximizing the network capacity [13, 14] or minimizing the cost of device deployment and/or network operation [12, 15, 16]. According to the methodologies to solve the optimization problem, these works can be further classified into two types, i.e., continuous and discrete cases. In the continuous case, it is assumed that there is no physical constraints and wireless network

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devices can be deployed at any location of the network region [17, 18]. Such problems can be solved by using some optimization algorithms like direct search and quasi-Newton methods [19]. However, in reality, wireless devices usually can only be placed at some candidate locations due to the physical constraints. Such problems can be formulated as the discrete cases of device deployment problems. The discrete problems are normally modeled as a mixed integer optimization problem to find out the optimal placement of devices in a given region (or among a set of users), such that all the users in the region can be served by the deployed network devices [15, 20, 21]. In [21], a relay node placement problem is investigated with the physical constraints of sensor nodes. In [15], how to place the minimal number of APs is studied under the physical and protocol interference models; and it is found that the underlying interference models have a significant effect on the AP placement problem. In [16], the optimization of base stations' number and locations is investigated in order to minimize the energy consumption of a cellular network, considering a practical case of non-uniform user distributions.

There have been limited works on network planning in sustainable wireless networks, which mainly focus on how to minimize the cost and network outage, i.e., some green wireless devices do not have sufficient energy to support normal operation or data transmission. The possibility and advantages of deploying a sustainable energy powered wireless system are reported in [22]. It is shown that solar or wind powered APs provide a cost-effective solution in wireless local area networks (WLANs), especially for APs installed in off-grid locations. In [1, 23], the traditional AP placement problem is revisited with sustainable power supplies. Their work focuses on placing a minimal number of green energy powered APs on a set of candidate locations to ensure that the harvested energy is sustainable to serve wireless users and fulfill their QoS requirement. The minimum-cost placement of solar-powered data collection BSs is considered in [24]. BSs are placed in a wireless sensor network, such that the outage-free operation of the sensor nodes can be obtained. In [25], authors jointly consider allocating transmitting power and deploying the green APs based on the harvested energy. In this work, a closed form power allocation scheme and an AP placement metric are proposed, and their theoretical analysis shows a dramatically improvement on overall throughput by using the proposed scheme.

2.2 Energy Modeling

One of the effective methods to prolong the battery life is to enhance the energy efficiency by designing an accurate analytic energy model [26–28]. In [29], a model which integrates typical WSNs transmission and reception modules with realistic battery models is proposed. Based on the battery models, they propose two battery power-conserving schemes for two M-ary orthogonal modulations. In [30], authors focus on designing time division multiple access medium access control protocols for healthcare applications in wireless body-area monitoring networks. They find that the proposed schemes can extend the lifetime of sensor nodes for the wireless body-area monitoring networks based on the theoretical and simulations.

The first addressed issue in many works related to green energy is sustainable wireless sensor networks with renewable energy [31–33]. In [34] and [35], authors show that such kind of prototypes can achieve near-perpetual operation of a sensor node. In WLAN mesh networks, the solar/wind powered AP is believed to be a more efficient method to save energy than energy efficient schemes in traditional AP, especially when the traditional power supply is not available. Different from traditional energy resources, we need to consider the inherently dynamic characteristics in both energy charging and discharging processes. Therefore, it is essential to characterize the variations in the analytical model of energy conditions. In [36], authors design a framework to model the remaining power of sensor nodes with and without green energy, and then the expression of network lifetime can be derived based on the energy model. In [37], the transmission policies for rechargeable nodes are considered to maximize the short term throughput, which refers to the amount of data transmitted in a finite time horizon. Based on the renewable energy model with discrete packets of energy arrivals, their proposed algorithm can successfully generate the optimal transmission policy, which can achieve the maximum short-term throughput and the minimum transmission completion time. In [38], the sustainable wireless rechargeable sensor network is proposed with mobile chargers charging multiple sensors from candidate locations. After that, an optimization model is developed to minimize the selected number of locations based on the energy recharging requirement of the sensors. Other works, such as [39, 40], mainly focus on the battery capacity and solar panel size of the BSs or APs, with an objective to mitigate the network outage by using the minimal cost of energy according to the recorded historical solar insolation traces.

2.3 Resource Allocation

Resource allocation is one of the most crucial methods to enhance the resource utilization of wireless networks [41–44]. Many works have been studied in various aspects of resource allocation, which include traffic scheduling and routing [45–47], optimal power management [48–50], energy efficient communication and cooperation [51–53], and adaptive sleep control of mobile devices [54–56], etc. Resource allocation [12, 57, 58] in infrastructure network can be formulated as an optimization problem such that the network performance, e.g. maximizing network throughput and maximizing network lifetime, etc., with fixed yet limited energy resource in traditional wireless networks is maximized, under various constraints including network connectivity, throughput, energy consumption and etc. The energy in these works is normally considered as a limited resource, thus these works generally target at maximizing the energy efficiency.

In sustainable wireless networks, the energy is sustainable in the long term yet dynamic in the short term, which may lead to intermittent energy supply in wireless network infrastructure devices [1]. Moreover, since the green wireless devices highly depend on their locations, which leads to uneven distribution of charging capabilities.

Thus, in order to balance the harvested energy and traffic demand, we should concern these characteristics and challenges of sustainable wireless networks.

So far, only a few works on resource management in wireless networks with green energy focus on maximizing the network sustainability, and most existing works aim at mitigating the node outage or minimizing the cost. In [39], the work focuses on solar panel sizing problem of the BS or APs based on the historical solar insolation traces, such that the network outage can be mitigated and the cost can be minimized. In [59], the problem of traffic scheduling for infrastructure of vehicular wireless networks is formulated into a mixed integer linear program with minimizing energy consumption as objective. In [60], authors propose a framework by jointly considering integrated admission control and routing under the multi-hop radio networks powered by green energy. Then, routing algorithms are proposed to improve network performance by using available energy. In [61], statistical power saving mechanism is proposed under solar-powered WLAN mesh networks. To balance the energy consumption with energy charging capability for each node, a control algorithm is developed to match the future load conditions and solar insolation for maintaining outage-free operations of the node.

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